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THE INFLUENCE OF HOLD TIMES ON FATIGUE CRACK GROWTH OF ALUMINUM--ETC(U)
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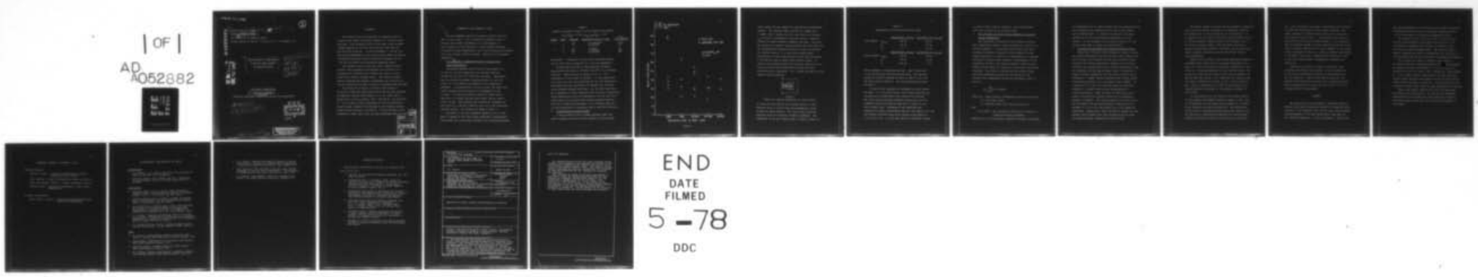

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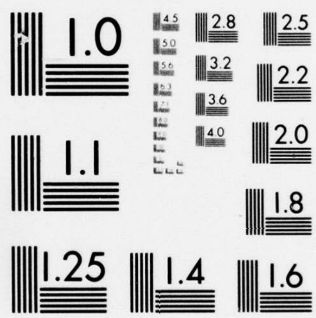

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ABSTRACT

The research into the influence of underload times on fatigue crack growth retardation behavior of aluminum alloys continued. The relaxation time for the lower yield strength overaged samples of 7075 was significantly less than for the 7075-T651 condition. In dry environment (~ 10% RH) the same strong dependence of the fatigue crack growth retardation on underload time was found as previously reported for the ~ 50% RH environment with everything happening slower.

The residual strain across the crack interface during fatigue crack propagation was measured and related to the ultrasonically measured crack closure load using a rigid strip finite element computer model. The relation between surface roughness and acoustic transmission as a function of load was determined and the influence of frequency was observed.

The influence of oxygen on fatigue crack growth in structural alloys was investigated using AES and SIMS analyses by comparing fatigue crack growth in 1.3 μPa vacuum and in oxygen-18 at 10 kPa for Monel, CPTi, 7075-T65 Al, and 2219-T851 Al. In all cases, strong indications of non bulk diffusion related oxygen transport was measured on the fracture surface formed during fatiguing in oxygen-18. Initial studies of the influence of water vapor using the same techniques were started.

SUMMARY OF 1977 RESULTS TO DATE

The main emphasis during the present contract year has been in four areas: 1) The influence of underload times on fatigue crack growth retardation, 2) investigation of crack closure, 3) the influence of crack surface roughness on acoustic energy transmission, and 4) the influence environment has on the fatigue fracture surface. These will be discussed separately.

1. The Influence of Underload Times on Fatigue Crack Growth Retardation

Previously reported results were for experiments run in room air at room temperature and relative humidity between 35% and 55% on Al 2219-T851 specimens. Experiments were run during the present reporting period to test the effect of a low humidity environment on the regardation phenomena. A plexiglass box was built around the sample and loading mechanism and filled with an atmosphere of dry nitrogen. The relative humidity lowered to about 8-10%, resulting in a slower fatigue crack growth rate by about a factor of two. Each overload was followed by relaxation at zero load for a variable length of time, as in the previously reported results. The results are shown in Table I.

The effect of the dry atmosphere appears to be to slow down all phases of the crack growth experiment, steady-state crack growth and crack growth following any overload-underload

TABLE I

Effect of Relaxation Time in a Low Humidity Environment

(K_{min}/K_{max} = 0.333, $K_{overload}/K_{max}$ = 2.5)

Sample	Spike	Humidity	Relaxation Time at 0 Load	Delay (1000 Cycles)
1	1	8%	no underload	270+
	2	8%	20 minutes	150
2	1	11%	13 hours	70
	2	11%	2 seconds	240
	3	11%	20 minutes	240

combination. A decrease in delay with increasing holding time at zero load is observed, as in the wet atmosphere.

To evaluate the effect of metallurgical variables, measurements were made on 7075-T651 and 7075 in an overaged condition. These results are shown in Fig. 1. The retardation in both cases is extreme. It only takes about one minute at a zero load underload for all the retardation associated with the overloads to be removed for the lower yield strength overaged condition. For the T651 condition, the retardation is still observed after 24 hours of underload. These observations could be explained by the fact that the growth during the overload goes through uncycled material, which has a lower yield strength in the overaged case and is more susceptible in relaxation than in the T651 condition.

2. Investigation of Crack Closure

A linear elastic finite element computer model was used to examine the crack closure behavior during fatigue

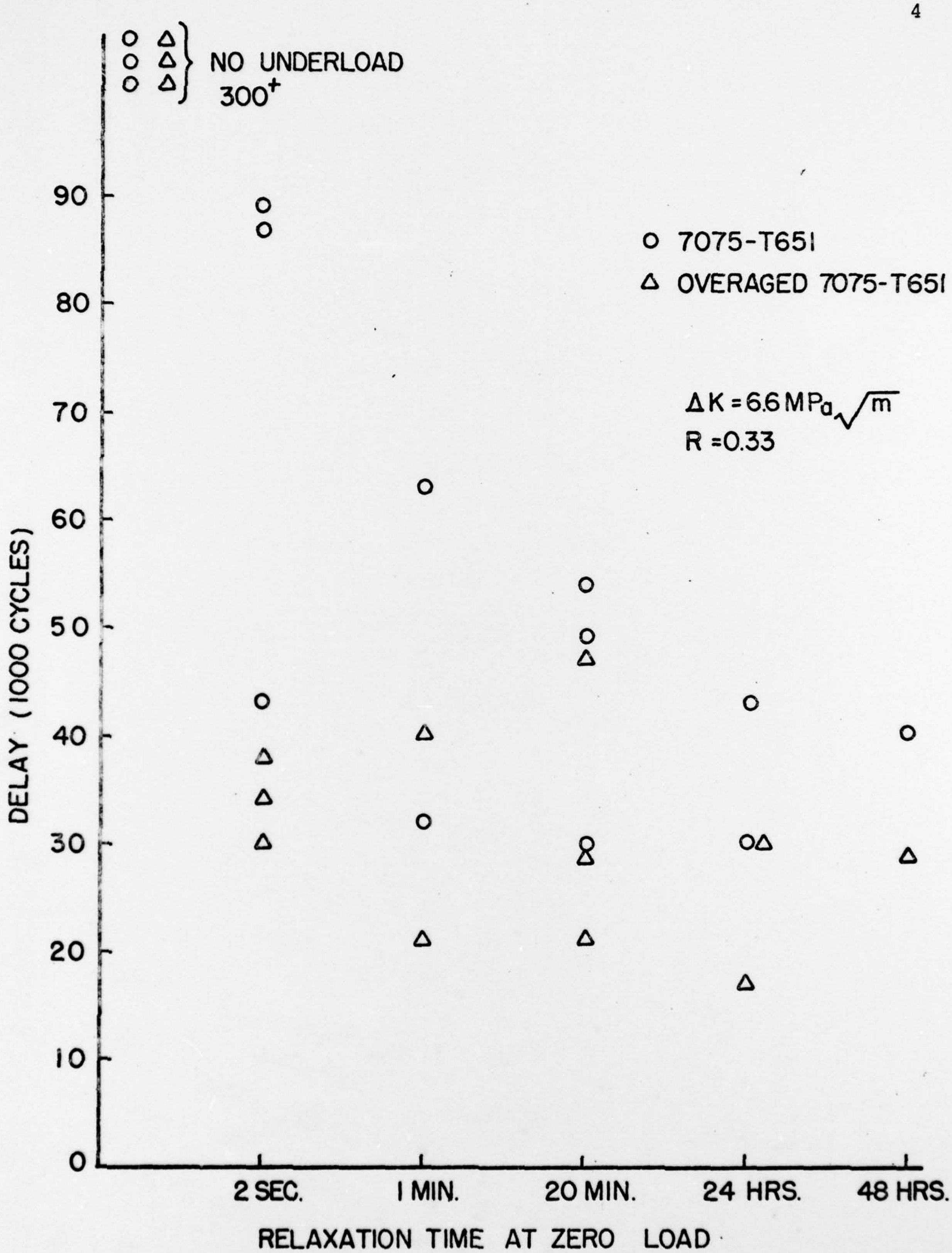
NO UNDERLOAD
300+
90
80
70
60
50
40
30
20
10
0
DELAY (1000 CYCLES)
7075-T651
OVERAGED 7075-T651
ΔK = 6.6 MPa√m
R = 0.33
2 SEC.
1 MIN.
20 MIN.
24 HRS.
48 HRS.
RELAXATION TIME AT ZERO LOAD

Figure 1

crack growth and was compared to experimentally determined results. The computer model consists of a sample with a "model crack," longer than the true crack by a distance r_y, with some incompressible external material inserted between the crack surfaces, propping them open. The crack may actually be closed a distance behind the true crack tip. The incompressible external material is made to represent the residual strain, d, in the crack closure model. Introduction of this rigid material allows the calculation of the applied load at which crack closure occurs. In addition the distance behind the crack tip that will be in contact and the stress distribution across the crack interface can be calculated. Fig. 2 shows the model for the compact tension geometry.

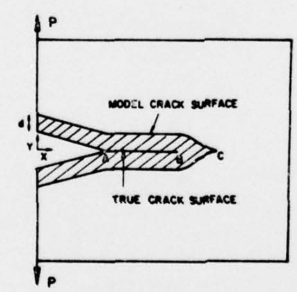

Figure 2

Model for Computer Simulation of Crack Closure

To check the calculations the residual strain, d, was measured using a clip-on gauge and propagating a crack through the gauge section. The crack closure load was measured using an ultrasonic acoustic transducer. The comparison of the two closure loads is shown in Table II,

TABLE II

Experimental and Calculated Closure Loads

		Experimental (±50 kg)	Calculated (d = 8.1 μm)
First Sample	P_{open}	450 kg	590 kg
	P_B	100 kg	100 kg
	P_C	0	-15 kg
		Experimental (±20 kg)	Calculated (d = 2.5 μm)
Second Sample	P_{open}	150 kg	180 kg
	P_B	50 kg	30 kg
	P_C	-100 kg	-5 kg

where agreement is exceptionally good. The d value used in the calculations was the measured value. The material tested was Al-2219 overaged 20 hours at 300°C in air from the T851 initial condition. The yield strength was about 200 MN/m^2.

A study of the influence of thickness on crack closure was made. A 2.5 cm thick fatigue crack growth specimen was fatigued until steady-state crack closure was observed. The crack closure was then measured acoustically with the transducer moved from edge to edge with no change in the crack closure load. Subsequently the experiment was repeated and closure measurements made for the sample at 2.5 cm and reduced from both sides after fatigue crack growth to 1.9 cm and 1.5 cm. In this case again no significant change

in crack closure load was observed. This clearly shows that crack closure is not an edge effect.

3. <u>The Influence of Crack Surface Roughness on Acoustic Energy Transmission</u>

Work continued in evaluating the ultrasonic acoustic wave transmission across a rough interface as a function of surface roughness. It has been clearly shown that using ultrasonic methods to evaluate the true extent of crack closure distance as a function of load applied to a specimen containing a fatigue crack requires a consideration of the compressive stress on the fracture surface, and the transmission factor which is a function of the stress and surface roughness. The extent of closure and the closure stress have been determined allowing the calculation of the acoustic wave transmission across the interface, which is given by

$$T_{AI} = \int_{x=0}^{x=a} T[\sigma(x), RMS]\,dx$$

where T_{AI} = total acoustic transmission across the interface

a = true crack length

x = distance along crack from load line to a

and

$T[\sigma(x), RMS]$ = the transmission factor as a function of stress and surface roughness

Therefore it is, in principle, possible to predict the amount

of transmission due to crack closure from the roughness-stress data presented here combined with the use of the elastic finite element model. It should be noted that the above analysis is for the instantaneous measurement of crack lengths. For NDT purposes the non-elastic behavior of the fatigue crack must be taken into consideration.

4. Influence of Environment on Fatigue Fracture Surface

Comparison of fatigue crack propagation rates in vacuum and oxygen environments was made for Monel 404, commercially pure titanium, and aluminum 2219-T87 and 7075-T651 alloys. Following the fatigue experiments, samples of the fatigue surfaces were analyzed with Auger Electron Spectroscopy (AES) and Secondary Ion Mass Spectroscopy (SIMS) to determine if oxygen had been transported into the material during crack propagation. Compact tension specimens were fatigue cycled through metal bellows in an ion-pumped vacuum chamber. At a pressure of 1.3 μPa, the crack was grown at relatively constant ΔK. Growth rate was thus established for a vacuum environment. Under constant ΔK conditions, crack growth rate should be constant except for environmental effects, if present. The isotope oxygen-18 of 99.9% purity was introduced into the vacuum chamber, backfilling to a pressure of 1 to 10 kPa, and growth rate in the oxygen-18 determined. Compositional depth profiles of oxygen into the fatigue crack surfaces were then obtained by use of inert ion sputter-etching, combined with AES and SIMS.

The surface formed in vacuum had been exposed to oxygen-18 longer than the surface fatigued in the oxygen-18, since it was formed prior to the introduction of the oxygen-18. It is expected that the profile from the fracture surface formed in vacuum represents simply oxidation and diffusion, while the fracture surface profile from the sample fatigued in oxygen-18 represents oxidation, diffusion, and any additional oxygen transport mechanism occurring during the fatigue crack propagation.

Results of the fatigue crack growth experiments showed an increased crack growth rate in the oxygen environment by a factor of 5 and 2 for Monel and titanium, respectively, with little or no increase apparent for the aluminum alloys. The penetration depth of the oxygen in each case as measured by AES and SIMS was greater in all cases when the fatigue crack was grown in oxygen-18, as shown in Fig. 3 for Al-2219 for AES. Using an estimated 50 to 100Å for the natural oxide thickness gives an estimate of the enhanced transport of 100 to 600Å.

An interpretation of the fatigue crack growth results is that gaseous environmental species, oxygen in this case, are transported into the metal during passage of a fatigue crack, possibly by mobile dislocations. The interstitial solute atoms in increased concentrations then interact with the base metal, significantly modifying the local plastic behavior and fracture strain in the vicinity of the crack

tip. This interaction for oxygen is apparently the strongest for Monel 404 and minimal for the alloyed aluminum. The oxygen influence on fracture strain could be the cause for the increase in growth rate. A second possibility would be associated with the crack closure concept. In the oxygen-18 case the observed change in oxygen penetration and postulated change in plastic behavior due to the transport of the oxygen could be expected to result in a smaller residual displacement in the wake of the crack, increasing the effective ΔK used in the crack closure model, consequently increasing the growth rate.

Studies were started on looking at how water vapor influences the fatigue crack growth. Initial studies of H_2 and H_2O were performed following the same scheme used for the oxygen-18. SIMS was then used to probe for the hydrogen with inconclusive results due to problems with the SIMS in measuring down to mass unit one in the 3×10^{-5} Ar atmosphere used for sputtering.

SUMMARY

The research into the influence of underload times on fatigue crack growth retardation behavior of aluminum alloys continued. The relaxation time for the lower yield strength overaged samples of 7075 was significantly less than for the 7075-T651 condition. In dry environment (~ 10% RH) the

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Many of the results reported here have been published and submitted for publication. The details and references associated with the studies have been submitted to AFOSR in the preprint and reprint form and have not been detailed in this report.

PERSONNEL INVOLVED IN RESEARCH - 1977

Graduate Students

Granville Sewell - Relaxation measurements, computer modeling of crack closure

John Jeffries - Acoustic transmission through interfaces

Capt. John Swanson (USAFIT) - Oxygen dislocation sweep-in

William Slagle - Relaxation measurements, crack closure measurements

Principal Investigator

Prof. Harris L. Marcus - Mechanical Engineering/Materials Science and Engineering

DISSERTATIONS, PUBLICATIONS, AND TALKS

Dissertations

1. John Swanson - M.S. Thesis, May 1977, "The Influence of Oxygen on Fatigue Crack Propagation."

2. Granville Sewell - M.S. Thesis, May 1977, "Relaxation and Crack Closure Effects on Fatigue Crack Growth in Al 2219."

Publications

1. Granville Sewell and H.L. Marcus, "The Influence of Underload Time on Crack Growth Retardation of Aluminum Alloys," Int'l. J. of Fracture 13, 247 (1977).

2. Granville Sewell and H.L. Marcus, "A Model for Fatigue Crack Closure Based on Surface Roughness and Residual Strain," Scripta Met. 11, 521 (1977).

3. John Jeffries, H.L. Marcus, and O. Buck, "The Influence of Fatigue Crack Surface Roughess on Acoustic Wave Transmission," Proceedings of the 11th Symposium on Nondestructive Testing, April 1977, San Antonio, Texas

4. H.L. Marcus, "Gaseous Environmental Effects on Fatigue Crack Growth," Proceedings of Conference on Environmental Degradation of Engineering Materials, ed. M.R. Louthan, Jr. and R.P. McNutt, VPI, p. 41 (1977).

5. J.W. Swanson and H.L. Marcus, "Oxygen Transport During Fatigue Crack Growth," to be published in Met. Trans. A.

Talks

1. H.L. Marcus, "Environmental Effects on Fatigue Crack Growth," invited talk, AIME Annual Meeting, Atlanta, 1977.

2. John Swanson, "Influence of O_2 on Fatigue Crack Growth," AIME Annual Meeting, Atlanta, 1977.

3. Granville Sewell, "Computer Model for Crack Closure," AIME Annual Meeting, Atlanta, 1977.

4. H.L. Marcus, "Fracture and Fatigue," Southwest Electron Spectroscopy Meeting, Texas A&M University, June 1977.

5. H.L. Marcus, "Gaseous Environmental Effects on Fatigue Crack Growth," invited talk, Environmental Degradation of Engineering Materials Conference, VPI, October 1977.

6. John Jeffries, "The Influence of Fatigue Crack Surface Roughness on Acoustic Wave Transmission," 11th Symposium on Nondestructive Evaluation, San Antonio, April 1977.

7. H.L. Marcus, "Environmental Effects on Fatigue Crack Growth," Oak Ridge National Laboratory, December 1977.

COUPLED ACTIVITIES

The following interactions involving our research took place during 1977.

1. Lecturer at the Fracture Mechanics Workshop, May 1977, SESA Conference.

2. Discussions with J. Gallagher, AFFDL, about the general direction of our research on several occasions, including at above SESA meeting. He did major review of proposal, suggesting increased emphasis on work statement topics 3 and 4.

3. Discussions with people in Metallurgy and Ceramics Division of Oak Ridge National Laboratory on fracture and fatigue crack growth, including colloquium on "Environmental Effects in Fatigue Crack Growth."

4. Continued interaction and technical exchange with Prof. M.E. Fine, Northwestern University; Lt. J.S. Santner, AFML; Dr. D. Davidson, SWRI; Prof. E. Starke, Georgia Tech, on fatigue crack growth in aluminum alloys.

5. Discussion with M. Amateau, Aerospace Corporation; O. Buck, Rockwell International; Prof. J. Tien, Columbia, on application of surface techniques to fatigue and fracture studies.

6. Discussion on quality assurance with Emilio Mendoza, Director of Quality Assurance, Kelly Air Force Base, San Antonio.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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